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ABSTRACT

This report summarizes the findings of one of fourteen panels that studied progress in space science applications and defined user needs potentially capable of being met by space-system applications. The study was requested by the National Aeronautics and Space Administration (NASA) and was conducted by the Space Applications Board. The panels comprised user specialists drawn from federal, state, and local governments and from business and industry. The Panel on Extractable Resources was charged with reviewing the use of information from space systems in the operation of the extractable industries, particularly in exploration for mineral and fuel resources. The Panel concluded that operation of remote sensing systems from space will improve understanding of geological processes. It also concluded that accurate measurement of large-scale crustal motions will lead directly to an improved theory of the processes of mineral concentration and to better selection of regions of the earth that merit exploration effort. (MH)

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Practical Applications of Space Systems

Supporting Paper 6

Extractable Resources

A Panel Report Prepared for the

Space Applications Board

Assembly of Engineering

National Research Council

SE 021 009

1974 SUMMER STUDY ON PRACTICAL APPLICATIONS OF SPACE SYSTEMS

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(July 1974)

PRACTICAL APPLICATIONS OF SPACE SYSTEMS

Supporting Paper 6

EXTRACTABLE RESOURCES

The Report of the
PANEL ON EXTRACTABLE RESOURCES
to the
SPACE APPLICATIONS BOARD
of the
ASSEMBLY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

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PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

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*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems.* National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

PANEL ON EXTRACTABLE RESOURCES

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INTRODUCTION

The Panel on Extractable Resources was charged with reviewing the use of information from space systems in the operation of the extractive industries, particularly in exploration for mineral and fuel resources. To this end, the Panel (1) reviewed the conclusions and recommendations of the 1967-68 NAS-NRC study, Useful Applications of Earth Oriented Satellites*, (2) reviewed the current state-of-the-art of remote sensing technology, (3) reviewed the contributions and capabilities of the Earth Resources Technology Satellite (ERTS) program, (4) considered the needs of the extractive industries in finding, developing, and producing resources, (5) considered the needs of the United States Government for formulation of land use and mineral resource policy, (6) outlined the requirements of the extractive industries for data from future unmanned satellites and from Spacelab, and (7) considered the benefits and costs of data generated by space systems in terms of the national interest.

The conclusions and recommendations presented are based on the fundamental premise that the survival of modern industrial society requires a continuing, secure flow of resources for energy, construction and manufacturing, and for use as plant foods. Discovery of the volumes and qualities of the great variety of earth resources needed to sustain this flow will tax the scientific and engineering ingenuity of industry and government. A level of success sufficient to maintain a healthy industrial society will require government policy as well as private and public investment to provide exploration scientists and engineers with all available data. Data from space systems will provide an important addition to information generated from aircraft-mounted sensors and ground field studies.

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*National Research Council. *Report of the Panel or Geology* (Panel 2) and the *Report of the Central Review Committee*. National Academy of Sciences, Washington, D.C., 1969.

THE EXTRACTIVE INDUSTRIES

IMPORTANCE OF PRODUCTS OF EXTRACTIVE INDUSTRIES

> "The development of American economic life is mirrored in the history of the production and use of materials.... Two centuries ago on an undeveloped continent, early settlers pushed back the frontier and fostered the growth of an agricultural economy and a nascent materials producing system. In the 19th century, labor and capital were imported, chiefly from Europe, to exploit our natural resources. These resources made a critical and continuing contribution to American life."*

A technologically based society depends on raw materials from which manufactured products are generated. The basic sources of wealth on which even the service industries are built depend on the incomes derived from the development, production and conversion of materials into essential or desirable products. The preponderance of the taxes which pay for government services are derived from the income generated from these industries.

In 1972 the minerals industries, which produce most of the energy and plant foods, more than half of the building materials, and all of the metals, sold $32 billion of products to feed a gross national product (GNP) of $1,152 billion. The value of mineral products is thus about 3 percent of the GNP, but mineral products are one of the basic generators of the GNP and provide very high leverage.

A chart illustrating the flow of mineral materials through the U.S. economic system was included in the 1973 Report of the National Commission on Materials Policy. An adaptation of this figure is shown in Figure I.

Population and per capita consumption increases will continue to place increasing demands on the extractive industries. This will be true even if the present trend toward zero-growth birth rate continues in some countries.

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*_Material Needs and the Environment Today and Tomorrow_, Final Report of the National Commission on Materials Policy. Submitted to the President and the Congress of the U.S., June 1973, p. 1-3.

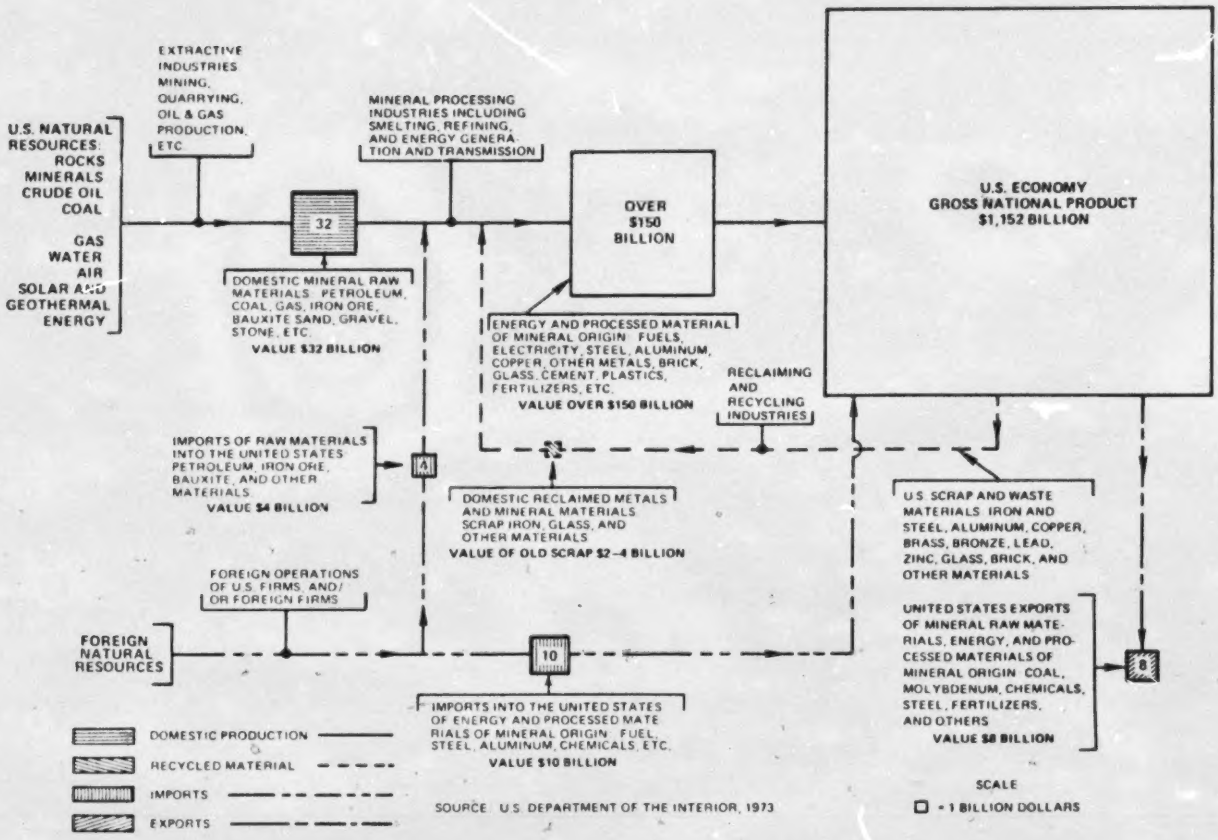
EXTRACTIVE INDUSTRIES MINING, QUARRYING, OIL & GAS PRODUCTION, ETC.
MINERAL PROCESSING INDUSTRIES INCLUDING SMELTING, REFINING, AND ENERGY GENERATION AND TRANSMISSION
U.S. NATURAL RESOURCES: ROCKS MINERALS CRUDE OIL COAL GAS WATER AIR SOLAR AND GEOTHERMAL ENERGY
32
OVER $150 BILLION
U.S. ECONOMY GROSS NATIONAL PRODUCT $1,152 BILLION
DOMESTIC MINERAL RAW MATERIALS: PETROLEUM, COAL, GAS, IRON ORE, BAUXITE SAND, GRAVEL, STONE, ETC.
VALUE $32 BILLION
ENERGY AND PROCESSED MATERIAL OF MINERAL ORIGIN: FUELS, ELECTRICITY, STEEL, ALUMINUM, COPPER, OTHER METALS, BRICK, GLASS, CEMENT, PLASTICS, FERTILIZERS, ETC.
VALUE OVER $150 BILLION
RECLAIMING AND RECYCLING INDUSTRIES
IMPORTS OF RAW MATERIALS INTO THE UNITED STATES: PETROLEUM, IRON ORE, BAUXITE, AND OTHER MATERIALS
VALUE $4 BILLION
4
DOMESTIC RECLAIMED METALS AND MINERAL MATERIALS: SCRAP IRON, GLASS, AND OTHER MATERIALS
VALUE OF OLD SCRAP $2–4 BILLION
U.S. SCRAP AND WASTE MATERIALS: IRON AND STEEL, ALUMINUM, COPPER, BRASS, BRONZE, LEAD, ZINC, GLASS, BRICK, AND OTHER MATERIALS
FOREIGN OPERATIONS OF U.S. FIRMS AND/OR FOREIGN FIRMS
FOREIGN NATURAL RESOURCES
10
UNITED STATES EXPORTS OF MINERAL RAW MATERIALS, ENERGY, AND PROCESSED MATERIALS OF MINERAL ORIGIN: COAL, MOLYBDENUM, CHEMICALS, STEEL, FERTILIZERS, AND OTHERS
VALUE $8 BILLION
8
IMPORTS INTO THE UNITED STATES OF ENERGY AND PROCESSED MATERIALS OF MINERAL ORIGIN: FUEL, STEEL, ALUMINUM, CHEMICALS, ETC.
VALUE $10 BILLION
DOMESTIC PRODUCTION
RECYCLED MATERIAL
IMPORTS
EXPORTS
SOURCE: U.S. DEPARTMENT OF THE INTERIOR, 1973
SCALE
□ = 1 BILLION DOLLARS

FIGURE I THE FLOW OF MINERAL MATERIALS THROUGH THE U.S. ECONOMIC SYSTEM*
(1972 estimates)

* Source: Second Annual Report of the Secretary of the Interior, under the Mining and Minerals Policy Act of 1970, 1973. Reproduced in *Material Needs and the Environment Today and Tomorrow*, 1973, p. 2-2.

It has been estimated that the world demand for raw materials will more than double by the end of this century. The world population and the gross domestic product as projected for the National Commission on Materials Policy to the Year 2000 are shown in Figure II.

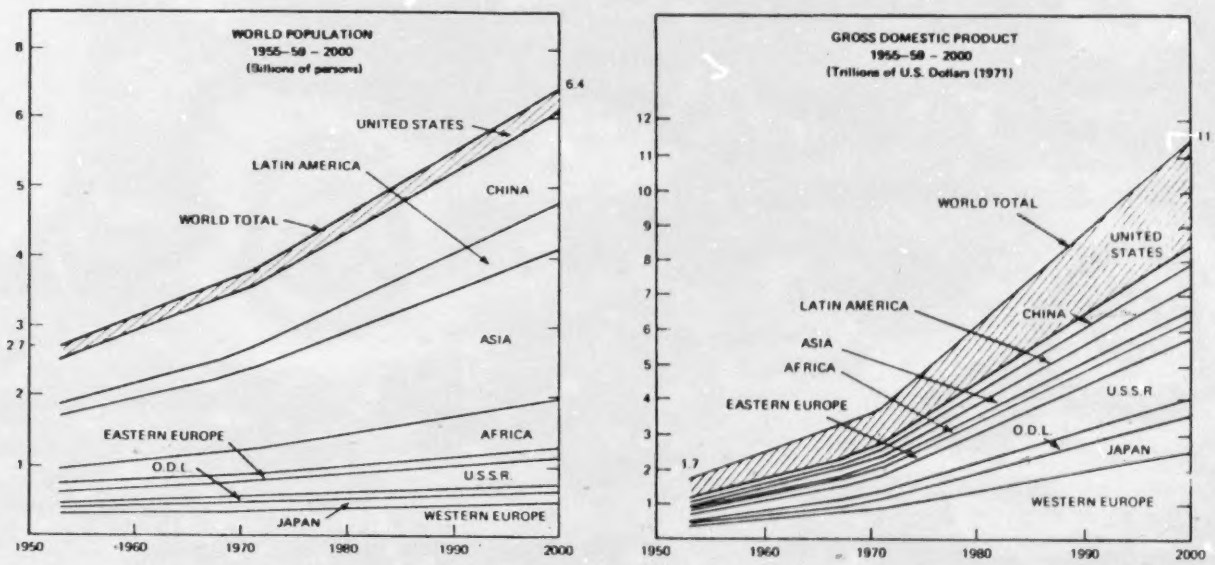

FIGURE II MATERIALS REQUIREMENTS IN A CHANGING WORLD*

Mineral raw materials are obtained from deposits of certain elements and minerals concentrated by natural processes in past geologic time. These deposits are finite and non-renewable. They must be continually replaced by the discovery, development and exploitation of new deposits. Most deposits of useful minerals are rare and hard to find. Every possible technique to aid in this search has to be utilized, no matter how remote are the possibilities of discovery. This is why the extractive industries account for approximately half the sales of ERTS data even though the industries are just beginning to use those data to their full potential.

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* Source: Malenbaum, W. "Materials Requirements in the United States and Abroad in the Year 2000," Research Project prepared for the National Commission on Materials Policy by the Wharton School, University of Pennsylvania, March 1973. Reproduced in *Material Needs and the Environment Today and Tomorrow*, 1973, p. 2-15.

The national needs for success in exploration are so great that no opportunity must be passed by. Every exploration plan that has prospects for aiding the program is insurance for the future. The survival of our industrial society depends on "...adequate energy and material supplies not only for the basic needs of nutrition, shelter, and health, but for a dynamic economy."*

Production of minerals returns more income per acre than all other uses of land except for dense urban development. Yet in the whole industrial history of the United States, only 0.3 percent of the land surface has been disturbed for extraction of coal, oil, gas, stone, sand, gravel, cement rock, metal and non-metal ores. About one-third of these disturbed lands have been returned to other uses. Under laws now developing, these lands will be returned to other beneficial uses more quickly than has been the case in the past. ERTS data will be useful for monitoring the progress of that return.

DISCOVERY, DEVELOPMENT, AND PRODUCTION OF MINERALS

The establishment of a new source of minerals is a long, difficult, and costly procedure involving many distinct activities. The first step is to identify potentially productive provinces within the earth's crust. The earth is neither chemically nor structurally homogeneous and certain kinds of minerals are restricted to certain geologic environments. For example, oil fields are found in sedimentary basins; chromium is found in association with igneous rocks rich in iron and magnesium.

The identification of new metallogenic or oil and gas provinces is based on the accumulated wisdom of generations of previous investigators whose work has developed extensive knowledge of the earth and has led to the development of theories of origin of mineral deposits. Synoptic views of large areas of the earth's surface obtained from space, together with data from various remote sensing devices on space vehicles and aircraft, can make invaluable contributions to knowledge and theory. It is unlikely that any single sensor can locate directly individual deposits. Nevertheless, the contributions to theories of origin to be derived from the space program could be a major step toward the improvement of the success of exploration programs.

Before extensive search programs are carried out in a province selected from an earth overview, a thorough assessment should be made of the political and economic factors within the boundaries of the province. Questions such as climate for investment and geographical accessibility are of vital importance in the decision to expend the vast sums of money needed to isolate geologic targets within the province.

The next step is the long, tedious, and costly process of reconnaissance. The process starts with employment of remote sensing devices long used in exploration, including aerial photography and airborne magnetic, electromagnetic, and radiometric surveys, and proceeds to geological interpretations of these findings where the geology appears to be favorable to the concentration of minerals. Those who finance exploration programs must be assured that the land

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*Letter of transmittal to the President and the Congress, Final Report of the National Commission on Materials Policy, June 1973.

is accessible, that tenure can be established, and that they can realize a reasonable return. Then begin the progressively more expensive geologic, geochemical, and geophysical surveys on the surface.

When the evidence, developed after enormously variable expenditures (from a few tens of thousands of dollars to tens of millions, depending on the target), gives sufficient confidence to proceed, the target must be carefully delineated. This evidence is obtained by detailed geophysical and geochemical surveys and finally by exploratory drilling, trenching, tunneling, sampling, and analysis. Only then can the deposits be developed by more extensive drilling and the construction of mining, concentrating, and refining facilities. In the case of oil fields, the development phase requires drilling of productive wells, construction of gathering pipeline, and refining facilities.

At each step of the way, the costs increase geometrically. The decision to proceed must be weighed at each step before the next order of expenditure is undertaken. Abandonment means virtually a total loss of previous expenditures. The risks involved are enormous and increase as evidence of new resources becomes more tenuous.

GOVERNMENT NEEDS IN POLICY FORMULATION

In addition to the needs of the extractive industries for information about the earth and its processes, various agencies of government with responsibility for promulgating land use, natural resources, and environmental policy need information about the earth and its processes and the ways in which the earth is being used by man. If the federal and state governments are to carry out their responsibilities in this field, they must understand the capability of the earth to sustain various kinds of uses and the environmental consequences of those uses. The extraction and processing of earth resources has an impact on the environment. The nature and degree of impact depends on the scale of the extractive enterprise, on the quality of its engineering, and, to a very large extent, on the geological environment of the area in which the enterprise is operating. Extractive industries mine "one crop" and after the resource is "harvested," the land may be restored to other beneficial use. Such restoration occurs in some areas through natural earth processes; in other areas, it requires reclamation and restoration efforts.

Government has need for (1) basic information on the geology and natural earth processes in the area of operation of the extractive industry and (2) information on the chemical, thermal, and other physical impacts of the extractive industry on the area, including the extent to which the industry's operations alter the composition of land, air, and water, affect the ecology, and change the configuration of the land surface.

The data needed take the form of repetitive imagery at a scale that permits measurement of the changing sizes of pits, dumps, and tailing ponds, the distribution of rock and mineral wastes, and other physical and chemical parameters which can be measured from photographs or other scanners and sensors. Repetitive analysis of the composition of air and water in the area of the activity are also needed.

The Panel on Extractable Resources recognizes the need for these data by appropriate agencies. The extent to which the need can be met by space systems and the specific requirements of these systems are discussed in the reports of the Panels on Environmental Quality and Land Use Planning.*

INSTITUTIONAL CONSIDERATIONS

Many of the current shortages in the supply of industrial materials arise in large measure from ignorance of the nature of the problem among decision makers. Theories, instead of knowledge based on experience, have led to seriously deficient policy decisions.

It is therefore essential that institutions designed to encourage or control resource development be responsive to those colleagues who are charged with the gathering of data and the use of those data in research into conservation and use. These are the people who are in daily contact with the industries and research agencies involved.

It is the firm belief of the Panel on Extractable Resources that those agencies of government that deal with the extractive industries must have a voice in the decisions involved in serving or regulating those industries, including decisions related to remote sensing. The Department of the Interior currently is the focal point for this wide range of interests and the proposed Department of Natural Resources would have a similar focal role. The Department of the Interior should be structured to bring together interests related to the extractive industries in mining, land management, reclamation, geological survey, parks, and fish and wildlife, under the coordinating responsibility of an Under Secretary who should speak with the authority both of knowledge and of appropriations. He should involve other federal, state, and private user organizations in the decision process, but should wield the power of appropriations to implement those decisions. Further, the Department of the Interior should be charged with continuing research to improve its services to users. If these institutional arrangements can be made within the Department of the Interior or its successor agency and effectively involve other government agencies which deal with the extractive industries, the Panel believes that there is no need for a new agency to deal with remote sensing for extractive uses.

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*Panel on Environmental Quality. *Practical Applications of Space Systems: Supporting Paper 7: Report of the Panel on Environmental Quality* and *Practical Applications of Space Systems: Supporting Paper 3: Report of the Panel on Land Use Planning*. Reports to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

STATE-OF-THE-ART OF EARTH-ORIENTED SPACE SYSTEMS

OPERATIONAL SYSTEMS

Improved weather information based on operational satellites and distributed by the National Oceanic and Atmospheric Administration (NOAA) is of great value to the extractive industries. Field camps, mines, and drill sites are commonly in remote and hostile environments where local weather data are scanty and where short-term weather forecasts are crucial. The benefits of improved weather information will continue to increase, especially as off-shore mining and oil production proceed to deeper water farther from shore. It is obvious that the extractive industries have a stake in the on-going research programs to improve weather observation from space and to achieve better short-range and long-range weather forecasts.

The TRANSIT navigation satellite is widely accepted within the extractive industries for navigation and position location. Marine seismic crews have used satellite navigation very effectively, with inertial guidance or bottom-reference sonar to interpolate between satellite fixes. Service companies have also engineered satellite receivers to locate base camps or other fixed installations. There is still a need of a capability for more frequent and more accurate position location.

Similarly, the extractive industries are prime customers for operational satellite communication systems. Voice communication worldwide is a continuing need, and data transmission by satellite will open up new possibilities.

EXPERIMENTAL PROGRAMS

The earth resources technology satellite LANDSAT (formerly ERTS) is the first spacecraft system designed specifically for earth resources surveys. It has provided experimental data for over 350 domestic and foreign investigations in various disciplines. The experience gained with this prototype of future space systems has been invaluable. Several applications in each discipline area have been proven feasible and have been identified as potential candidates for quasi-operational tests. The orbital parameters, sensor spatial quality, and data quality have been adequate for the Department of the Interior to seriously consider acquiring a modified ERTS for the first operational system.

Although the ERTS is a U.S. system, more than 100 foreign investigators, sponsored by their governments, are conducting evaluations of U.S. supplied data for resource applications.

The data acquired by ERTS are in the public domain and obtainable for the cost of reproduction at the U.S. Department of the Interior's Earth Resources Observation System (EROS) Data Center at Sioux Falls, South Dakota. EROS has provided complete cloud-free coverage of the United States. These data have been used for a substantial number of experiments based on the study of lineaments and signatures related to mineral occurrences. A good example is the use of a large-scale mosaic comprising several states, including Utah and Colorado, that shows an east-west trending fault associated with the Colorado mineral belt. The ERTS photographic transparencies available from the EROS Data Center have resolution to 80 meters and 16 radiation intensity or gray levels. The magnetic tapes of the same coverage have the same inherent resolution; however, they provide 64 gray levels and are used for computer processing of the data that have produced the pictures.

Despite the successes and the knowledge gained from ERTS, this satellite remains the "Model T" of earth resources space remote sensing systems. However, ERTS-1 has had a lifetime beyond the initial one year expectation; the multispectral scanner was still functioning as of July 1974. Many improvements and advances are necessary to satisfactorily meet application requirements. Increased temporal and spectral coverage are required for many applications. A fifth band in the thermal infrared region is under development for a later ERTS mission; however, extension of spectral coverage to the microwave region is necessary for all weather data acquisition and offers considerable promise for many applications.

The Earth Resources Experiment Package (EREP) of Skylab was the first manned and the second space earth resources survey system. It consisted of a set of experimental instruments to evaluate the following:

Man's role in earth resources surveys from space

Earth resources film return systems

Applications of active and passive microwave systems

High resolution photographic systems

Narrow-band multispectral scanning systems including near-, mid-, and thermal-infrared bands.

The EREP multispectral camera has a resolution of 30 meters and the terrain camera 10 meters. Final results of the experiments are not yet available, however, preliminary findings are encouraging. The sophisticated nature of the multisensor, multispectral data acquired in three missions during the 9-month activity period lends itself to computer processing and analysis. Preliminary evaluation of the EREP data indicates they will be useful for future geologic reconnaissance and mineral exploration.

RECOMMENDATIONS OF THE 1967-68 SUMMER STUDY

The Geology Panel of the 1967-68 Summer Study on Useful Applications of Earth-Oriented Satellites recommended:

1. Immediate (within three to five years) low-angle color photography of North and South America by sun-synchronous satellite and immediate (within three to five years) side-looking radar coverage by aircraft of the same two continents. A geological resources satellite, called GEROS-1, was estimated to require a budget of either $38 or $57 million, depending on instrumentation. It was recommended that GEROS-1 be operational in three to five years.

2. Research and development on the spectral signatures of rocks, minerals, and soils with a first phase for 5 years at $1.7 million per year and a second phase for 10 to 12 years at $1.2 million per year. It was contemplated that the work should progress from field and laboratory studies in the first phase to aircraft and spacecraft experimentation and testing in the second phase.

It is the judgment of the Panel on Extractable Resources that the development of ERTS (approximately $160 million) and EREP (approximately $135 million) in a 5-year term has more than carried out the recommendations for synoptic photographic coverage made by the Panel on Geology of the 1967-68 summer study.

The 1968 panel's recommendation that there should immediately be implemented a program designed to produce synoptic aircraft-based radar coverage of North and South America was not carried out for several reasons. Such an operational aircraft project was not appropriate for NASA to fund within its authority for experimental programs. No other agency considered it appropriate to its mission to fund the program.

The 1968 panel's second recommendation has not been completely carried out. To date, only about $1 million has been spent by the U.S. Geological Survey on research on spectral signatures of rocks, minerals, and soils, as against the approximately $10 million recommended for the first 5-year phase of this project. NASA also reduced its level of funding for rock signature research because early results were disappointing and there appeared to be more productive opportunities in other areas. A major problem is that variations in atmospheric conditions and sun angles cause the signature of the emitter to be so variable as to make recognition uncertain. Funding was restricted to the most promising areas of inquiry, namely, microwave sensors and vegetation reflectance in mineralized areas.

In the present Panel's judgment, the modifications made of the recommendations of the 1967-68 Panel on Geology were sound research decisions in light of results obtained from then-current programs and of funding realities.

FUTURE EARTH-ORIENTED APPLICATIONS OF SPACE SYSTEMS

Some of the applications of future systems will require advancements in the technology. Other applications will demand no new technology, but rather will stress the need for continuity of systems already in use on an experimental basis. Some of the needs can be satisfied by aircraft photography. However, the use of satellite observations will permit geological explorations on a much broader scale. Some of the requirements for which new technology will have to be applied are necessary not only to meet technical needs but also to deal with legal and economic factors. Some examples follow.

Potential deposits are often sought in remote locations which lack sophisticated bench marks, grid systems, or other references for position determination. It is often necessary to make repeated visitations to prior sites of exploration; therefore, an accurate position determination system is necessary. When a deposit is discovered, it is necessary to know whether or not the find is on protected lands, and here a distance of a few meters is significant. The Panel hopes that the advent of commercially available back-pack equipment for position determination will occur soon.

In seismic exploration it is necessary to collect the data in the field, send it to a computer center for processing, and then make another seismic test based on the processed data from the prior test. This is often an iterative process. In some known cases, this round trip to and from the computer center has required as much as four months. Communications capability that would permit digital data handling would make possible almost real-time analysis for seismic data, which could amount to significant economic savings. The Panel recognizes that there is a need for small, low-cost transportable earth terminals for handling digital data.

GEODETIC MEASUREMENTS

Better definition of the relative motion of tectonic plates will contribute to understanding of the metallogenic process and may disclose new regions which merit detailed exploration.

Critical to the observation of plate motion is the resolution of the measurement. The parameter to be measured is the velocity of one plate relative to another. The velocities are extremely low, of the order of 1 to 10 centimeters per year. The relative velocity must be computed for measurements of the position of each plate at various times over long periods. If a sufficient

number of measurements are made, the velocity may be calculated to within the necessary accuracy.

The patterns of earlier plate movements, if they can be ascertained, may make it possible to delineate land masses which are not currently experiencing relative motion, but which may nevertheless have potential for mineral exploration.

A system for providing this geodetic information should meet the following requirements:

1. Readings annually for a decade
2. Position sensing with resolution of $\pm$ 3 cm
3. Data tabulated as calculated results
4. Global coverage

Better understanding of the long-term movement of tectonic plates could lead to the possibility of predicting earthquakes.

CONTINUOUS SYNOPTIC IMAGERY

The most important contribution of ERTS-1 consists of synoptic coverage of the earth in a continuous sequence of 185 km by 185 km scenes at constant sun angle. The alternative is the classical aerial photomosaic, composed of many small pictures, taken for reasons of economy under different sun-angle illuminations; the result is a "checker board" effect making the comparison of tonal differences among areas on the mosaic difficult.

Operational Requirements

Although the geology of the earth does not change rapidly, much might be learned by observing the effects of solar heating, snow cover, different atmospheric transmissions, and vegetation cover. The operational requirements for synoptic imagery of the earth related to the extractive industries are thus subdivided as follows:

Yearly requirements: Land slides, volcanic activity, erosion, coastal changes, tailing dump growth, and forest clearance-cutting scars require yearly updating.

Seasonal requirements: Vegetation changes require 4 to 6 seasonal coverages during the year.

Daily requirements: To achieve cloud-free synoptic views, daily coverage for approximately 30 days during each season should provide about two scenes per target area.

Time-of-day requirements: In mountainous areas, illumination of both the sunlit and the shadow side of the mountain requires two views each, mid-morning and mid-afternoon. The heat capacity data (long wavelength infrared bands) require additional data collection between 2 and 4 a.m. without sun illumination. Sun illumination data for the preceding day are required for data reduction.

Sensor Requirements

The sensors should have the capacity to record the surface scene in the reflected sun light bands -- blue-green, yellow-orange, red-deep-red, near IR -- and in the long wavelength IR bands both night and day.

Data Requirements

In the data collection by synoptic imagery, items to be considered include:

Format: The data should be available in phototransparencies and digital magnetic tapes for scenes having an area of 185 km by 185 km, annotated as to latitude, longitude, date, local time and/or sun angle.

Accuracy: Data should be accurate within the following limits:

1. The resolution should be $\pm$ 30 meters in the near future and $\pm$ 15 meters in the 1980's. (Present resolution of about $\pm$ 80 meters is adequate for experimental purposes.)

2. Imaging should continue to provide 16 grey levels for phototransparencies and 64 grey levels for magnetic tapes.

Coverage: The scenes should be taken over the global land masses and the continental shelves.

OPERATIONAL REQUIREMENTS FOR HIGH RESOLUTION TARGET IMAGERY

Coverage of selected target areas of approximately 80 km by 80 km with a resolution of 10 meters is required for detailed geological target evaluation.

Time-of-day requirements: The picture should have minimum cloud or sand storm interference and shadow effects are undesirable in mountainous terrain. Multiple coverage may be required to minimize clouds, sand storms, and shadows.

Data requirements: The data should be available in phototransparencies and digital magnetic tapes, annotated as to latitude, longitude, date, local time, and/or sun angle.

Accuracy: Resolution should be ± 10 meters. Images are required in three basic colors with the ability to distinguish 16 levels in the scale of color saturation.

Coverage: The scenes should be taken over selected areas on the global land masses and the continental shelves.

POSITION LOCATION

An exploration party needs to know its position accurately because (1) the party will need to return to sites previously visited and (2) accurate descriptions of position are essential in acquisition of properties.

Hemispherical coverage over global land masses and continental shelves should be provided. Each overpass of the satellite should provide latitude and longitude to be recorded at the site on magnetic tape. Accuracy should be within ± 30 meters in the near future and within ± 10 meters in the 1980's.

COMMUNICATIONS

There is a need for communications between extractive industry central locations and crews in the field. Voice communications capabilities are needed for personal liaison purposes and digital communications capacity is needed for data (for example, seismic data which could be processed more quickly and economically at a central location).

Operational Requirements

Both voice and digital communications links should be available at least once a day between company headquarters and field sites.

Date Requirements

Format:

1. Two way voice communication is needed. Scrambler capability should be provided to meet security requirements.

2. A digital data transmission capability of up to 10^7 bits per second will be needed in the 1980's.

Accuracy: Error rates should be compatible with best coding practices (approximately one error in 10^6 bits). Signal-to-noise ratio should be suitable for magnetic tape recording.

Coverage: Communications capability should be provided over the global land masses and continental shelves.

SPACELAB EXPERIMENTS

Operational Requirements

The Panel believes that in the 1980's, most of the research problems concerning spaceborne reconnaissance for the extractive industries will be solved. The previously discussed problem of rock signatures will be well understood. The problem remaining will be the removal of operational restrictions, such as cloud cover, sand storms, and vegetation masking. The Spacelab offers the opportunity for experimenting with systems to remove these restrictions.

Sensor Requirements

The sensors should be multifrequency, high-resolution radars, operating:

As reflectometers, measuring in the active mode, the radar cross section of a resolution element;

As radiometers, measuring in the passive mode, the microwave radiance of a resolution element.

Data Requirements

Format: The data should be displayed to the operator on-board Spacelab to allow in-flight evaluation and should be recorded on magnetic tape.

Accuracy: Data acquired should provide resolution of $\pm$ 10 meters and an amplitude accuracy to within 1 percent.

Coverage: Areas covered should be global land masses and continental shelves.

BENEFITS

Because it is essential to the national welfare to ensure the discovery and production of earth resources and to develop a sound, balanced national policy on mineral resources and land use, it is the Panel's judgment that the United States government should make such investment as is necessary to continue the earth resources programs using unmanned satellites and Spacelab to produce the kinds of information previously discussed. The benefit of the program is an improved capability to find new mineral deposits and to develop sound national land use and mineral resources policy.

The extractive industries and various government agencies concerned with land use and environmental quality have already received benefits from earth-oriented space programs. These include:

Long-term contributions to basic knowledge about the earth and its processes that will result eventually in an improved theory of formation of mineral deposits.

An important new dimension (synoptic imagery from space) in the exploration phase of mineral development.

Recurrent data on the impact on the earth of extractive industries.

Important improved capabilities in (1) communications and in determining precise location on the earth's surface; and (2) weather advisories for the increasing mineral-industry activities in and on the oceans and in remote land and ice ares.

In considering these benefits to the extractive industries and to the nation, the question to be asked is: To what extent and at what cost will space systems data either (1) substitute for data now obtained from aircraft and ground surveys, or (2) add a capability not now possible through aircraft and ground surveys?

For basic earth science, space-systems data provide a repetitive synoptic view not possible with other techniques and make possible precise measurements of earth processes, such as tectonic plate motions, not available through other techniques.

In mineral exploration programs, space-systems data can substitute for high-altitude aerial photography. Space-systems data cannot substitute for low-flying aircraft photography or sensing or for ground surveys. The cost differential between the present cost of high-altitude aerial photos and the appropriate share of the cost of space systems imagery to be allocated to mineral exploration remains to be determined. Of much more importance is the added capability provided for mineral exploration by space systems. The Panel believes that this added capability does increase the probability of discovery of mineral deposits but finds it impossible to assign a dollar value to this increased capability. Application of cost-benefit methodology to exploration is subject to the same limitations as application of cost-benefit methodology to other research and development programs.

In monitoring the impact on the earth of the extractive industries, it is possible that a space systems capability for high-resolution imagery could be substituted for aircraft monitoring. The degree of substitution and relative costs remain to be determined.

In position location and weather forecasting, it is clear that the extractive industries have benefited enormously from improved capabilities offered by the systems already operational. This contribution is susceptible to cost-benefit analysis and should be so evaluated.

As a caution, considering the demonstrable benefits that have and will accrue to the sellers and users of earth resources data obtained from space systems, it is unnecessary, and indeed counter productive, to overstate benefits or to contrive quantification.

CONCLUSIONS AND RECOMMENDATIONS

The Panel concludes that operation of remote sensing systems from space is vital to the maintenance of our industrial society. Research and development into space remote sensing systems improvement and support at a level needed to reduce cost is essential. Many of the needs of user communities for specific sensors are common. Therefore the cost should not be charged wholly to any single user community. The nation benefits universally from improved weather forecasting, land use knowledge, position location, knowledge of scientific processes, availability of materials through exploration and development, etc. Therefore, it is sound policy to finance the basic scientific and engineering program from public funds.

GENERAL RECOMMENDATIONS

Generally, the Panel recommends that:

Development, maintenance, and operation of remote sensing systems designed to meet the broad needs of society become a permanent activity of the federal government.

The government continue to charge a development agency with research and development on hardware and sensing systems and with operating the space vehicles.

The government design its space programs so that the user communities control the course of the program through the budgeting procedures within existing agencies.

SPECIFIC CONCLUSIONS AND RECOMMENDATIONS

Specifically, the Panel concludes and recommends:

1. Conclusion: Improved understanding of geologic processes on a global scale and accurate measurement of large-scale crustal

motions will lead directly to an improved theory of the processes of mineral concentration and to more enlightened selection of regions of the earth that merit exploration effort.

Recommendation: NASA should continue to develop the technology for determining relative positions of points on the surface of the earth to such an accuracy that relative motion of tectonic plates can be observed and spatial variation of the solid-earth tide can be mapped.

2. Conclusion: Imagery from satellites provides a new dimension in the reconnaissance phase of oil and mineral exploration. More research is required to exploit the full range of sensor capabilities and to develop sophisticated programs of data analysis.

Recommendation: NASA should develop and test sensors to cover the full spectrum of anticipated needs, providing continuous synoptic imagery with an option of high resolution imagery for selected targets.

3. Conclusion: The most effective use of remote sensing from satellites will require involvement of the user on a continuing basis. Although sharing spacecraft and sensors among users is clearly desirable, individual data sets and programs of data analysis will be unique to some users. It is necessary that each user be able to work with an agency that understands its unique needs.

Recommendation: The Department of the Interior or its successor agency should continue to have responsibility for providing remote sensing data to users in the extractive industries and for extending data analysis services.

4. Conclusion: The extractive industries are already making use of the TRANSIT satellite position determination system. There is a need for commercially available portable ground equipment, capable of determining position to within 10 to 30 meters on a continuous basis, at any point on the globe.

Recommendation: Advanced satellite navigation systems should be emphasized, with the objective of considerably improving the state-of-the-art of navigation systems in the public domain.

5. Conclusion: It is likely that individual companies will request high-resolution imagery of specified targets. The more definitive and detailed the images become, the more likely it will be that companies will want sole access to such data.

Recommendation: The government should address the question of user costs and user participation in data acquisition, as it relates to users from the private sector.

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